NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. I. March 1887. No. 3.

This Association, as a Body, is not responsible for statements or opinions of any of its members.

PROCEEDINGS.

QUARTERLY MEETING AT BOSTON,

DECEMBER 7, 1887.

The New England Water-Works Association held its quarterly meeting at the Quincy House, Boston, Wednesday, December 8, at which about forty members were present. There were no set papers, but there was an abundant flow of informal discussion, and a highly interesting and satisfactory meeting was the result.

Dinner was served at 1:30 P. M., at which President Rogers, of Lawrence, had Alderman Pettee, of Newton, on his right and Secretary Glover on his left, and without special order the following gentlemen on either side: Messrs. Rotch, of Boston, Coggeshall, of New Bedford, Allen, of Hyde Park, Billings, of Taunton, Noyes, of Newton, Holden, of Lowell, Learned, of Boston, Perkins, of Watertown, Grannis, of New Haven, Coffin Valve Co., of Boston, Kieran, of Fall River, Hancock, of Springfield, Hall, of Quincy, Sprague of Malden, George Woodman & Co., of Boston, Stacy, of Marlboro, Jenks, of Pawtucket, Kelley, of New York, Baldwin, of Boston, Welch, of New York, Tilden, of Boston, Forbes, of Brookline, Brown, of Charlestown, Chadwick Lead Works, of Boston, Kent, of Woonsocket, Wilcox, of Waltham, Harris, of Waltham, Beals, of Middleboro, Fuller, of Boston, R. D. Wood & Co., of Philadelphia, Babcock, of Nashua, and Taylor, of Worcester.

After cigars had been lighted, President Rogers called the company to order, and in a few well chosen words expressed his pleasure at the interest shown by the large attendance and lively interchange of ideas, and then called upon several gentlemen for any remarks that might be suggested by the occasion. Alderman Pettee spoke of the importance of preserving the perfect purity of public water-supplies. Mr. Harris started a discussion upon the source from which wells or galleries near a running stream receive their supply, and detailed some experiments made at Waltham, Mass. Mr. Rotch, of Boston, gave a brief account of some experiments which he made some years ago for the Boston and Providence Railroad Company upon a well at Mansfield, Mass., to determine the company's liability to certain mill-owners who claimed that the water in the well came from their mill-stream. Observations on the temperature of

the well and river waters which Mr. Rotch had made gave the case to the railroad company.

Mr. Fuller thought that in such a case the stream was indirectly robbed, because the ground-water taken from the well might have found its way into the stream.

Mr. Noyes thought that the interception of water had been declared by the Supreme Court of Massachusetts to be cause for damage.

Mr. Henry C. Meyer, editor of the Sanitary Engineer of New York, was introduced and emphasized the necessity for checking the waste of water which, with a few and notable exceptions is going on in our American cities, by calling attention to the valuable property which the city of Liverpool, Eng., has been obliged to purchase in order to secure the area which will be overflowed when the Vynwy Dam shall be completed.

Mr. Babcock gave some account of an unusually abundant supply of ground-water which is obtained at Nashua, N. H.

SPECIAL MEETING AT BOSTON.

JANUARY 12, 1887.

This may be counted as the first of the monthly gatherings of the Association, which have proved so successful during the winter now drawing to a close, and was held at Young's Hotel on the date above given.

There were no set papers at this meeting, but their place was well supplied by the very free discussion and informal speaking which followed the creature comforts of the dinner. President Rogers briefly welcomed the members and guests, and called upon Mr. Howland, who gave in his easy manner an informal description of the work going on under his direction, though under the immediate oversight of Mr. George A. Ellis, at Racine, Wisconsin. Mr. Howland spoke also of the new water works at Montgomery, Ala.

The Racine work involved the laying of a suction pipe out into Lake Michigan and contained points of special interest. At Montgomery, a search for water had to be made, and the driven well was employed. The question as to the permanency of a supply from driven wells was raised and Mr. Noyes said that he had not been able to detect any falling off in the supply of the wells at Newton, and spoke of the importance of defining the limits of the underground reservoir which always supplys any system of driven wells.

Mr. Brackett gave some account of the experiments made in Boston with a machine for cleaning out main pipes, and stated that a machine made for this purpose in Fitchburg, Mass., seemed to give better results in the Boston pipes than did the apparatus made by Mr. E. H. Keating of Halifax, N. S., because the latter machine could not get by the corporation cocks whose ends came through the pipe and so formed an obstruction. The Fitchburg machine has the scrapers so arranged as to yield to the resistance of the projecting taps, and yet sufficiently rigid as to remove the incrustatious upon the interior of the pipe. These tubercular incrustations are quite soft until dried and exposed to the atmosphere. The capacity of some uncoated 4 and 6 inch pipes which had been in use about 25 years was increased 300 per cent. by the use of this machine.

Messrs. Darling, Brackett, Rogers, Brown, and others, discussed the methods of caring for fire hydrants during cold weather so as to reduce the danger from freezing to a minimum, and Mr. Coggeshall gave a brief statement of facts in connection with the growth of algæ in the New Bedford reservoir. Attention was called to the fact that the Massachusetts Legislature of this winter would be asked to pass a law which should put all water companies under the supervision of a state commission having powers analagous to those of the present state railroad commission.

The meeting adjourned to the second Wednesday in February.

SPECIAL MEETING AT BOSTON,

FEBRUARY 9, 1887.

The February meeting of the association was held on the 9th inst., at Young's Hotel in Boston, at which there were present about fifty-six of the active and associate members.

Among the guests were Hiram F. Mills, C. E., of the Massachusetts State Board of Health, and C. E. Chandler, C. E., of Norwich Conn.

Dinner was served at 1:30 P. M., and at its close President Rogers presented Mr. Mills, as the first speaker, who spoke briefly of the newly organized State Board of Health, and of what it proposed to do in matters which have especial interest for the association.

All inland waters in Massachusetts are now under the care of this board, and no plans for water-supply or for sewage disposal can be carried out without first being submitted to the board for approval. The board has asked for an appropriation of $30,000, and proposes to expend one-third of this amount in having chemical and microscopical examinations of some 2,000 different samples of water collected from all over the State. For one year samples are to be collected monthly, and after that time semi-annually. The first examinations will have especial importance, as furnishing a standard for future comparisons.

Mr. Mills called attention to the increase in the impurity of the Merrimac at Lowell and Lawrence since 1873—viz., thirty-six per cent. at the former and fifty-seven per cent. at the latter—and concluded by asking the members of the association to co-operate with the State board in protecting and improving the quality of the inland waters of the State.

Mr. Mills' remarks were followed by questions and discussion from Messrs. Tidd, Fitzgerald, Holden, Rotch, Darling, and President Rogers.

Professor George F. Swain, of the Massachusetts Institute of Technology, read an able paper upon the "Influence of Forests upon Rainfall," which will be found upon the succeeding pages.

The paper was briefly discussed by Desmond FitzGerald, C. E., in a serious vein, and by Commissioner W. M. Hawes, of Fall River, in his happy and humorous manner.

Mr. Fitzgerald supplemented the account of various experiments which is contained in Professor Swain's paper by a brief description of his arrangement of tanks sunk in the ground and filled with earth, and so connected by pipes and weighing tanks as to enable him to measure the relative amounts of percolation and evaporation under a given set of conditions.

The veteran engineer, Phineas Ball, of Worcester, spoke briefly upon the subject of Professor Swain's paper, and referred to the fact that he had found more water in a cubic foot of earth taken from an open lot than in another foot taken from within a forest.

A paper by Albert F. Noyes, C. E., of Newton, upon Driven Wells, was postponed until the next meeting.

PAPERS.

REMARKS OF HIRAM F. MILLS, C. E., OF LAWRENCE, MASS., AT THE SPECIAL MEETING OF FEB. 9, 1887.

Gentlemen of the New England Water Works Association.—

Your President has kindly invited me to tell you what the State Board of Health proposes to do in those matters in which you have an especial interest and wherein we desire your hearty co-operation.

You have all doubtless received from our Secretary copies of the law of 1886 giving to the Board of Health charge of the inland waters of the State. I have selected passages in this law in which we have a common interest and find these include nearly the whole law. I will however read the more important.

Commonwealth of Massachusetts.

[Chap. 274.]

AN ACT TO PROTECT THE PURITY OF INLAND WATERS.

Be it enacted, etc., as follows:

SECTION 1. The state board of health shall have the general oversight and care of all inland waters and shall be furnished with maps, plans and documents suitable for this purpose, and records of all of its doings in relation thereto shall be kept. It may employ such engineers and clerks and other assistants as it may deem necessary: *provided*, that no contracts or other acts which involve the payment of money from the treasury of the Commonwealth shall be made or done without an appropriation expressly made therefor by the general court. It shall annually on or before the tenth day of January report to the general court its doings in the preceding year, and at the same time submit estimates of the sums required to meet the expenses of said board in relation to the care and oversight of inland waters for the ensuing year; and it shall also recommend legislation and suitable plans for such systems of main sewers as it may deem necessary for the preservation of the public health and for the purification and prevention of pollution of the ponds, streams and inland waters of the Commonwealth.

SECT. 2. Said board shall from time to time as it may deem expedient, cause examinations of the said waters to be made for the purpose of ascertaining whether the same are adapted for use as sources of domestic water supplies or are in a condition likely to impair the interests of the public or

persons lawfully using the same, or to imperil the public health. It shall recommend measures for prevention of the pollution of such waters and for removal of substances and causes of every kind which may be liable to cause pollution thereof, in order to protect, and develop the rights and property of the Commonwealth therein and to protect the public health. It shall have authority to conduct experiments to determine the best practicable methods of purification of drainage or disposal of refuse arising from manufacturing and other industrial establishments. For the purposes aforesaid it may employ such expert assistance as may be necessary.

SECT. 3. It shall from time to time consult with and advise the authorities of cities and towns, or with corporations, firms or individuals either already having or intending to introduce systems of water supply or sewerage, as to the most appropriate source of supply, the best practicable method of assuring the purity thereof or of disposing of their sewage, having regard to the present and prospective needs and interests of other cities, towns, corporations, firms or individuals which may be affected thereby. It shall also from time to time consult with and advise persons or corporations engaged or intending to engage in any manufacturing or other business, drainage or refuse from which may tend to cause the pollution of any inland water, as to the best practicable method of preventing such pollution by the interception, disposal or purification of such drainage or refuse: *provided*, that no person shall be compelled to bear the expense of such consultation or advice, or of experiments made for the purposes of this act. All such authorities, corporations, firms and individuals are hereby required to give notice to said board of their intentions in the premises, and to submit for its advice outlines of their proposed plans or schemes in relation to water supply and disposal of drainage or refuse. Said board shall bring to the notice of the attorney-general all instances which may come to its knowledge of omission to comply with existing laws respecting the pollution of water supplies and inland waters and shall annually report to the legislature any specific cases not covered by the provisions of existing laws, which in its opinion call for further legislation. [*Approved*, *June* 9, 1886.]

In performing these duties we ask your co-operation in considering the sources of pollution of your several water supplies, aiding us to obtain as exact data as possible upon these points together with the best means of prevention of such pollution, and to notify us of any persistent violations of law which are harmful to the water under your charge.

During the past year we were asked advice in regard to the water supply of the town of Bradford on the Merrimac and in considering that river as a source of supply we found the following condition of the river. I read from our report to the Legislature.

"By the analyses of Merrimac River water, made in 1873, 1879 and 1886, we find that in 1873, when the amount of impurity in the water was sufficiently small to allow the water of the river, both at Lowell and at Lawrence, to be accepted as good drinking-water, the impurities then added by the sewage of Lowell and the refuse from the factories were so modified by flowing nine miles, and by being diluted by the increase in quantity

of water, due to an increase of one-seventh of the drainage area, that the water at Lawrence above the city was as good as that above Lowell; but in 1886, we find that, with substantially the same quantity of water flowing in the river, the per centage of impurities from animal and vegetable putrefaction as shown by the albuminoid ammonia, has increased above Lowell by 36 per cent., and above Lawrence by 57 per cent.; and that the impurities poured into the river at Lowell are now greater than the exposure to the air in flowing nine miles and the increased dilution can overcome, leaving the water above Lawrence with 12 per cent. more of impurities, due to animal and vegetable putrefaction, than that above Lowell, and 57 per cent. more than it contained when the water works were established at Lawrence, and now approximating the undetermined border line beyond which the water would be unfit for drinking.

These results are obtained in September and October, when the quantity of water flowing in the river was about double the minimum quantity known to flow during a week of severe drought.

At times of drought, and during the winter when the river is covered with ice, and the water having received the sewage of Lowell is not exposed to the air until it reaches the reservoir of the Lawrence Water Works, the per-centage of impurities is probably increased notably above that given by the table; but of these conditions we have no analyses.

In considering the duties of the Board, under section 2 of chapter 274 of the Acts of 1886, we have concluded that the interests of the public require that, for one year at least, chemical and, when necessary, biological examinations should be made once a month, of all waters supplied for domestic purposes, by Water Boards, Water Commissioners and Water Companies, within the State; and that thereafter such examinations should be made at intervals not exceeding six months.

It is only by such a series of examinations, including the varying circumstances of the year, together with exact data concerning the sources of pollution, that the Board can determine to what extent the different sources are becoming polluted, and be enabled to study the measures necessary for prevention.

In considering the table of analyses of the Merrimac River water still further, we find that, although polluted by the factories of Lowell and Lawrence, and such sewage as was then discharged, the analyses of 1873 showed the water above Bradford and Haverhill to be as good as that above Lowell; but this result no longer obtains, for the analyses of 1886 show the water above Bradford to have 34 per cent. more impurity than that above Lowell, and 81 per cent. more than it had in 1873, rendering it, unquestionably, an unfit source for the domestic water supply of Bradford.

This result is not unexpected; the same result has happened to every watercourse in the State which happens to lie in the midst of a populous and growing district. A gradually increasing mass of pollution reaches a point at which the stream is no longer able to neutralize it, either by dilution or by any of the so-called processes of oxidation, and a condition of things may be arrived at as disgusting as that of the Blackstone at Millbury, or of Alewife Brook in Cambridge and Somerville, or of the North River at Salem.

In no one of these instances was the introduction of sewage a nuisance originally, and in no one of them would it have been possible to say in advance just where the saturation point would be reached.

The only method thus far for determining the purity of water has been by chemical analysis; recent investigations have however, shown many defects in the processes in use, and the attempt has been made to examine by the microscope, or by other methods known to trained observers, the lower forms of life, which are present at all times in waters in a natural state.

It seems to this Board, as has already been said, very important that examinations of the various water supplies of the State should be made by the best-known methods at regular intervals, both for the purpose of assuring to the various cities and towns all the certainty derivable from this source as to the healthful condition of their drinking-water, but also with the hope of arriving at some more definite information as to the substances constituting the harmful element and the best means of detecting them.

The money spent for this purpose would be much less than would be spent to obtain the same results by the various water companies, public and private, throughout the State; and it would be fair to assume that uniformity in the scientific methods employed, and regularity in the seasons of examination, would give results of much greater value than any hitherto obtained.

RECOMMENDATION.

In order to make the series of examinations above outlined, including monthly analyses of all waters used for domestic supply in the State, and biological examinations of the certain waters injuriously affected by animal life, together with chemical analyses of other inland waters, to conduct experiments contemplated, upon the purification of sewage and refuse from industrial establishments, and to make the necessary investigations in order to advise cities, towns, corporations and individuals in regard to the best method of assuring the purity of intended or existing water supplies, and of the best method of disposing of their sewage, the Board estimates the sum of $30,000 will be required."

Signed :

HENRY P. WALCOTT'
ELIJAH U. JONES,
JULIUS H. APPLETON,
THORNTON K. LOTHROP,
FRANK W. DRAPER,
HIRAM F. MILLS,
JAMES WHITE,
} State Board of Health of Massachusetts.

Of this $30,000 about one third will be needed for the expense of transportation and chemical and biological examinations of the waters of the State. We expect to make from 2500 to 3000 such examinations. About one third in experiments upon disposal of sewage and refuse from manufacturing establishments, and one third in investigations, in order to advise cities, towns and individuals in regard to the best sources of supply and the best method of assuring the purity of supply and of disposal of sewage. In regard to the latter you will see that the Legislature does not propose to sanction the taking any water or adopting any system of

sewerage until the Board of Health having regard to the needs and interests of all other parties advises it to be done.

You gentlemen can appreciate that the duties by this act imposed upon the Board are onerous, but they are so important that we hope the performance of them will prove a blessing to the Commonwealth. The method of performing them will depend first upon the appropriation that is made. The members of the Board of Health have no compensation for their services, and whatever the appropriation is, so much of it as we deem necessary to spend goes into the work, the remainder returns to the Treasury.

If you, who from your knowledge of the sources affecting injuriously your water supplies can judge better than your fellow citizens the value of a systematic series of monthly examinations including the varying conditions of the year, with observations taken at the time of taking the samples showing comparatively the quantity of water flowing from the source; if you believe that the Board of Health will by employing the best chemist we can find and the best examiner with the microscope and other methods of studying the animal life and germs of disease in the water, will make the best use of $10,000 of the State's money that can be made with it, in examining from 2000 to 3000 samples of drinking water, you will, without being asked, see that the members of the legislature from your districts are sufficiently informed that they will vote the appropriation required. The appropriation made, our engineer will consult with you and determine the best place or places for taking the samples. One of them will be preferably from a very short service pipe taken from the main pipe a short distance from the reservoir. The bottles will be sent from our laboratory to you, you will be asked to fill the bottles on the appointed day of the month, at the place or places arranged by our engineer, and return them by the first express that the water may be as fresh as possible when examined. If we are examining 200 samples a month we shall have the chemists necessary to make eight analyses a day, and will, of course, have to depend upon your promptly filling the bottles and returning them on the day appointed that our business may be carried on systematically and economically; the Board, of course, paying the expressage, and relying upon you to co-operate in filling the bottles and making and sending such notes as may be agreed upon with our engineer to indicate the stage of the stream or pond from which you draw. These are the general plans upon which we propose to work for the year after receiving the appropriation, and that we hope, may be promptly made that we may begin examinations when the ice is upon our streams and ponds. In this we confidently ask your coöperation, because your intelligence upon this subject enables you to see the importance of having these examinations made under the varying circumstances of the year, that we may know the conditions now existing, and as a standard to which all future examinations may be compared.

I thank you, gentlemen, for your cordial greeting and interest in our work and shall depend, with confidence, in your cordial coöperation.

THE INFLUENCE OF FORESTS UPON THE RAINFALL AND UPON THE FLOW OF STREAMS.

By Professor George F. Swain.

The subject of the paper is one upon which much has been written, and yet upon which there has been much difference of opinion, except as regards some well-known and very apparent facts. The effect of forests upon the flow of streams is generally understood, in its broad aspect, if not in detail. But with regard to their effects upon the precipitation, writers have not yet succeeded in coming to an agreement. Upon a subject which has been so widely and so ably discussed, I cannot pretend to say anything new or striking, and I should not have ventured to present to this Association a paper on this topic unless I had been especially requested to do so by your Executive Committee.

Before discussing the effects of forests upon rainfall, it will be necessary to briefly state the conditions upon which precipitation depends, and to consider the source of the rainfall. The source of our rain is, of course, principally the sea, and from the sea the moisture proceeds in a never-ending cycle, being first evaporated, then carried over the land, precipitated, and finally returned to its source. In some inland regions this cycle may exist independent of the ocean, some inland sea taking its place. But the cycle occurs nevertheless just the same. The seas, then, are primarily the source of our precipitation, and the amount of vapor brought from the sea to the land will depend upon the evaporation from the surface of the sea, and upon the prevailing winds which blow over the region in question. From tropical seas the evaporation is large, and if this vapor is carried directly upon the land and exposed to conditions favorable to condensation, abundant rains will be the result.

Now what are the immediate causes of precipitation? All air contains vapor to some extent, but the maximum amount which it is able to contain depends upon its temperature. Thus the amount of vapor which a given weight of air, at a given pressure, is able to contain at a temperature of 20° C. is about four times that which it can hold at a temperature of 0° C. Briefly stated, the entire phenomenon of precipitation depends upon a certain mass of air containing a given quantity of vapor, being cooled to such a temperature that it can no longer contain that vapor, the excess of which falls, therefore, as rain or snow. This cooling may be brought about in various ways—by the air being deflected upwards by a mountain range, by the mixture of two masses of air of different temperatures, or in other ways. Precipitation will, therefore, be increased by any agency which tends to cause a greater quantity of aqueous vapor to be brought to the region in question, or to effect the more complete precipitation of that vapor. Thus we are all familiar with the facts that the rainfall is in general greatest in the tropics; —in the quarters from which the prevailing winds blow,—near the coasts, and on hills and mountains.

Now let us consider for a moment what becomes of the rain which is precipitated upon the land. Only a portion of it flows back to the sea,

the remainder being evaporated on the way. There is thus a cycle within a cycle, and the aqueous vapor in the air of a given region is derived not *entirely* from the ocean, but partly from that source and partly from the trees, streams, and soil of the region itself. We have the vapor from the ocean carried over the land, reinforced as it goes by the evaporation from the land itself, precipitated and flowing back to the sea, but losing, as it flows, some considerable quantity by evaporation. Now considering that we have to do with an extended area, there seem to be only three ways in which the rainfall over that area may be increased; viz.: 1st, by increasing the amount of vapor brought from the ocean; 2nd, by increasing the amount derived by evaporation from the land; 3rd, by the precipitation of a greater proportion of that which is carried by the atmosphere. Now it is not possible that forests can affect in any way the amount of vapor brought from the ocean: hence we may dismiss that from consideration. But it is very possible that they may increase or diminish the amount evaporated from the soil, and in this way affect the amount precipitated. For instance, suppose that the amount of precipitation over a large area is 30 inches, of which 20 inches comes from the ocean and 10 inches from evaporation from the soil, rivers, etc. Evidently of these 30 inches precipitated, 20 will flow off and 10 be re-evaporated and eventually be again precipitated. Now if in some way we can cause a larger evaporation from the soil, say, 20 inches instead of 10 inches, than we shall finally change the condition of things and have 20 inches coming from the ocean, 20 inches added from the land, and therefore a precipitation of 40 inches, and of these 40 inches, 20 inches will be re-evaporated and 20 inches returned to the ocean. As already expressed, we have a cycle within a cycle, and in the process just described we have simply increased the quantity of water traversing the inner cycle. There has been no increase or decrease in the flow of the streams or in the amount of vapor brought from the ocean, but simply an increase of the evaporation; we have added 10 inches to the quantity annually evaporated and precipitated, completing its cycle independent of of the ocean. Of course, such a change as here described could only be effected gradually, and until a permanent regime were established, the annual flow of the streams would be diminished. Thus, if the change just alluded to were accomplished in one year, the streams would in that year discharge only 10 inches instead of 20.

Any cause, then, which increases the evaporation from the land may be reasonably supposed to increase the rainfall.

We shall discuss farther on the effect of forests upon evaporation, and shall see that their total effect is very uncertain; but an example may be noted here which illustrates the remarks just made. It is commonly claimed that the rainfall of the prairie States, reaching as far west as the uncultivated grazing country of eastern Colorado has been increased since the extensive settlement and cultivation of this region. It is stated that records at Fort Leavenworth show a precipitation of 30.96 inches during the nineteen years just preceding the occupation of the State by white settlers, and of 36.21 inches during the nineteen years just following such occupation.* That there has been a marked increase of rainfall seems to be the universal testimony throughout this

*Science, 1885. page 12

region, and it is the opinion held by men of science as well as by the common population. Leaving out of consideration the question whether the evidence thus far adduced is sufficient to prove unquestionably the fact, such increase may be very easily explained in view of what has just been stated. Before the occupation by white settlers, the plains were the abode of Indians and wild beasts. Their surface was baked hard in the summer sun and trampled under the continual tread of herds of animals. The rain falling on this surface was rapidly shed, where the ground was sufficiently inclined, and was quickly carried into the streams and discharged. The settlement of the country has been followed by the cultivation of the soil. The moisture precipitated is now retained upon the ground, allowed to percolate, absorbed by growing crops; a much larger proportion than before is evaporated, and springs long dry have become almost perennial. Naturally an increase of rainfall should follow these changes, and at the same time the flow of the streams should have become more regular. Probably the same total quantity of water is discharged by the rivers now as 50 years ago, but continued records, if they had been kept, ought to show that it is discharged more uniformly at present.

The increase in the rainfall cannot, in the present case, be attributed to the influence of trees, for although orchards have been planted, and other trees grown as a protection against the wind and sun, yet there has been no appreciable increase in the total wooded area—at least none sufficient to account for the changes which it is claimed have occurred.

Thirdly, we saw that the rainfall could be increased by any influence causing the precipitation of a greater proportion of the vapor in the atmosphere, such as a change in the mean annual temperature. If a region becomes colder, the change would tend to produce an increase in the rainfall; if warmer, the reverse—unless the change were great enough and the area large enough to influence the winds of the globe, in which case the resulting change in rainfall might be different in different cases. This influence on temperature is the only one which is of sufficient importance to be considered in this connection. Later investigations on the effect of woods upon temperature are in tolerable agreement. In the first place, forests impede the circulation of the air, thus diminishing evaporation from any moist surface, and if the winds are cold, they render the cold less sensible. Examples are cited by Marsh showing how the removal of forest, and the consequent exposure to prevailing winds, has been accompanied by a considerable climatic change, which is different, however, according as the winds which the forests shield against are cold or warm. But however important this function of the forest as a shield against the wind may be with regard to agriculture, it may be dismissed from consideration in connection with the question of precipitation. Regarding the general effect of forests on the mean annual temperature, Marsh says, "It seems probable that in every particular case the result is, if not determined, at least so much modified by local conditions which are infinitely varied that no general formula is applicable to the question," and he quotes Gay Lussac's remark that "we have not yet any positive proof that the forest has in itself any real influence on the climate of a great country, or of a particular locality." Later experi-

ments, however, of Becquerel, of Boussingault, and especially of Ebermayer, tend to show that forests do exert a slight frigorific tendency, and that the mean temperature of cleared land in the tropics and in temperate zones is about one degree Centigrade above that of the forest. Ebermayer found that in winter the effect of woods was very small, but that at night the woods were much warmer than the cleared ground.

Although this influence of the forests upon temperature, by bringing the air nearer to its point of saturation, may reasonably be supposed to have *some* effect upon the precipitation, it can scarcely be expected that such effect will be very great. The precipitation of vapor takes place in the clouds, not in the woods except to a very small extent, and inasmuch as forests increase the temperature at some hours of the day, and decrease it at others, their effect being moreover very much greater at some seasons of the year than at others, it seems scarcely probable that a difference of 1° C. in the mean annual temperature can be of any great—perhaps not of any perceptible—influence on the total annual rainfall.

It would seem, therefore, that while forests may, by lowering the average temperature, induce at times some slight increase in precipitation, yet their principal effect must be sought by tracing their effects upon the evaporation; and that if it can be definitely shown that they appreciably increase this, it will reasonably follow that they increase the rainfall. It may be noted here that the experiments of Ebermayer showed that the absolute humidity of the air was almost precisely the same within a forest as without, in each season and month, as well as on the average through the year. The relative humidity, however, was greater in the forest, particularly in the summer, when its temperature is most perceptibly lowered. This effect is of course due in part, if not wholly, to the fact that as the mean temperature of the air within forests is lower than without, the same amount of vapor will bring it nearer to the point of saturation. Should it ever be proven that the effect of forests is to diminish or not to affect the total evaporation, it will be extremely difficult to conclude that they can appreciably increase the mean annual rainfall.

Let us now briefly consider what grounds are usually given in proof of the statement that forests increase the rainfall. The most frequent argument advanced is the fact that the removal of forests has been accompanied by a drying up of springs, a lowering of streams, and a dimunition of the power at different mill privileges. Marsh well expresses the facts as follows: "In writers on the subject we are discussing, we find many positive assertions about the dimunition of rain in countries which have been stripped of wood within the historic period. But these assertions very rarely rest upon any other proof than the doubtful recollection of unscientific observers, and I am unable to refer to a single instance where the records of the rain-gauge, for a considerable period before and after the felling or planting of extensive woods, can be appealed to in support of either side of the question. The scientific reputation of many writers who have maintained that precipitation has been diminished in particular localities by the destruction of forests, or augmented by planting them, has led the public to suppose that their observations rested on sufficient proof. We cannot affirm that in none of these cases did such proof exist, but I am not aware that it has ever

been produced. * * * * * The effect of forests on precipitation, then, is by no means free from doubt, and we cannot positively affirm that the total annual quantity of rain is even locally diminished or increased by the destruction of the woods, though both theoretical considerations and the balance of testimony strongly favor the opinion that more rain falls in wooded than in open countries. One important conclusion at least, upon the meteorological influence of forests is certain and undisputed, the proposition, namely, that within their own limits, and near their own borders, they maintain a more uniform degree of humidity in the atmosphere than is observed in cleared grounds. Scarcely less can it be questioned that they tend to promote the frequency of showers, and if they do not augment the amount of precipitation, they probably equalize its distribution through the different seasons." These last conclusions of Marsh, however, cannot yet by any means be considered as proven.

Marsh proceeds to say that the strongest evidence to which he can refer, in support of the proposition that the woods produce an increase of rainfall, is furnished by the observations of Mathien, sub-director of the forest school at Nancy. His measurements, continued for three years, from 1866 to 1868, show that during that period the mean annual rainfall in the centre of the wooded district of Cinq-Tranchées, at Belle Fontaine, on the borders of the forest, and at Amance, in an open cultivated territory in the same vicinity, was respectively as the numbers 1000, 957, and 853. Fautral and Sartiaut placed at an elevation of six meters above a grove of oaks and elms of twenty years' growth and eight of nine metres height, pluviometers and other meteorological instruments, and like instruments at the same elevation in the open ground, 300 meters from the forest. In the months from February to July inclusive, the rainfall above the trees was found to be 192.5 millimeters and, during the same period, 177 millimeters in the open ground. In regard to experiments such as these, it is to be remembered that rain-gauges placed at a certain height above a forest would not be comparable with those placed at the same elevation on open ground. That is, a gauge at an elevation of 100 feet, or, say, 20 feet above a forest would not be comparable with one at an elevation of 100 feet above the open ground. Experiments have shown that a guage on a level with the ground may collect six per cent. more rain than one a foot above the ground, while a difference of from 10 to 15 per cent. may exist between a gauge at the level of the ground and one 20 feet above it. Now, if a gauge be placed 20 feet above a forest, aside from the fact that the tops of the trees will not be level by any means, yet the top of the forest will, to some extent be equivalent to the ground, and the gauge will be in some degree similar to one 20 feet above the ground and not 100 feet. At any rate, two gauges at the same absolute height will not be comparable, and when such differences as 10 or 15 per cent. are noted between gauges at slightly different elevations, it would seem to be entirely unscientific to attribute much weight to observations such as those which have been quoted.

Again, the drying up of springs or the apparent diminution of water in streams is entirely inadequate to prove that the cutting down of forests has in the slightest degree diminished the rainfall. It is well known that

forests are great regulators of the flow of streams, that they feed the springs and diminish the frequency and violence of inundations. But that their destruction actually diminishes the total quantity flowing off has never been proved, and would indeed be a difficult thing to prove. Sir G. Wex, in a work entitled "Ueber die Wasserabnahme in den Quellen, Flüssen und Strömen, bei gleichzeitiger Steigerung der Hochwasser in den Culturländern,"—translated and published by the Bureau of Engineers, U. S. A., has undertaken to prove that the average stage of certain large rivers in Europe has gradually decreased; and he attributes this to the felling of the forests. On the other hand, Hagen, well known as the most eminent hydraulic engineer of Germany, has investigated the question, and by means of an elaborate mathematical analysis, arrived at the conclusion that the observations do not show that the *average stage* of the water is falling on any stream but the Elbe.* But even these discussions are of slight value with reference to the question whether the total annual discharge is increased or not, because they are based simply on observations of the gauge readings. Now it would be a very possible thing for the average gauge reading at a certain station to be less this year than last, and yet for the total quantity discharged to be greater this year than last. The flow at any given time depends not only on the gauge readings, but on the slope of the water surface, which may be very different according to circumstances, with the same gauge reading. In fact, Humphrey's and Abbot found that. at a certain station, the Mississippi River discharged at one time 50 per cent. more water than at another time although the height of water was precisely the same in the two cases. When a river is rising, the discharge is larger than when it is falling, with the same height on the gauge. Now the effect of removing the forests is to increase the suddenness and violence of floods. And since a flood wave is always very much steeper on the front side than on the back—it is by no means impossible that the quantity of water passing during a flood may be greater than that deduced from the gauge readings, notwithstanding the fact that the rise takes place more rapidly than the fall. Observations on gauge readings alone, then, are of little or no value in proof of the assertion that the total annual discharge of a stream is increasing or decreasing, unless the increase or decrease were much greater than could reasonably be attributed to the influence of woods alone. Nor would daily and accurate measurements of the flow itself suffice to prove a change in the rainfall, for as we shall see presently, the conditions affecting the relation between rainfall and discharge are numerous and complex, and an increase in the rainfall might even be under certain circumstances accompanied by a decrease in the total discharge of the streams.

The same remarks may be made regarding the comparative frequency and height of inundations. Especially in this country, popular deductions are often made on insufficient data. Inhabitants along the banks of a stream conclude that their river is becoming more variable, or that it is discharging a greater quantity of water, because for a few successive years freshets are more frequent and more violent than usual. But mete-

Zeitschrift fur Bauwesen. 1881, pp. 18 to 26.

orological phenomena are easily forgotten, and lose in vividness as they recede in time, and if the records of past years on that same stream could be consulted, it would very likely be found that many years ago there had been even more violent freshets than those of recent years. If we take the records of high water which happen to be at hand regarding the Ohio River, we might conclude that a gradual change was taking place in its flow, because since 1860, the high water mark had seemed to show a progressive rise culminating in the disastrous freshet of two years ago; and if we were particularly imaginative we might hasten to draw the conclusion that this was due to the destruction of forests on the drainage basin. But if we look further back, we shall find that in 1832 there was a freshet which rose to within a few feet of the high water mark of two years ago, and the probability really seems to be that the destruction of woods in the Ohio basin has thus far had but very little effect, if any, upon the flow of the river.

Cases are sometimes cited of islands of comparatively small area on which the destruction of forests has been followed by a drying up of the springs and a diminution of the rainfall. But here, again, no measurements are at hand on which to found the statement regarding the rainfall. For instance: Dr. Rogers, of Mauritius, gives this testimony, "So late as 1864, the island was resorted to by invalids from India, as the "pearl" of the Indian Ocean,—it being then one mass of verdure. That, when the forests were cleared to gain space for sugar-cultivation, the rainfall diminished, the rivers dwindled down to muddy streams, the water became stagnant in cracks, crevices, and natural hollows, while the equable temperature of the island entirely changed, drought was experienced in the midst of the ocean, and thunder showers were rarely any longer witnessed * * * * The hills were subsequently planted with trees, and the rivers and streams resumed their former dimensions."

Again, it is stated that the Island of Ascension was formerly almost a barren rock. The supply of water was very scanty, derived solely from a few springs, and water was often brought from the Cape of Good Hope and even from England for the needs of the garrison. About twenty-five years ago, the planting of trees and shrubs and the cultivation of the soil were vigorously undertaken, as a result of which the water supply is said to have increased until now it is excellent, and the garrison and ships visiting the island are supplied with an abundance of water.* But here, again, it may easily be the case that the rainfall has really not been changed and that the absence of forests was simply accompanied by a very variable character of the rivers, which at times were torrents and so highly charged with sediment as to be entirely unsuited for use, while at others they were practically dry.

The last instance which I will bring to your attention is that cited by Marsh from Boussingault. The rivers which rise within the valley of Aragua, having no outlet to the ocean, form by their union the Lake of Tacarigua, or Valencia, about seven miles long. The waters of this lake had for many years been retreating, new islands made their appearance, and many supposed that a subterranean outlet permitted the discharge of the water to the ocean. Humboldt, however, ascribed the diminution of

Popular Science Monthly, 1881, page 177.

its waters to the cutting down of the woods. Twenty-two years later, the valley was again explored and it was found that the waters of the lake were rising. During the interval which had elapsed the valley had been the scene of war; plantations had been abandoned, and the forest, which grows so rapidly in the tropics, had soon recovered a large proportion of the soil. It was at once concluded that this re-foresting of the valley was the cause of an increase of rainfall, and thus of the increase of the waters of the lake. It can easily be shown, however, that other causes than a change of rainfall may have produced these effects. It is only necessary to imagine that the evaporation from the lake had been altered; and it would no doubt be perfectly possible to frame a hypothesis based upon the known effects of woods in shielding from the winds, and in diminishing the violence of freshets and the sudden discharge of the rainfall, which might account for the changes which have been noted.

We see, therefore, that it is extremely difficult to prove that the forests increase the rainfall, and that all indirect arguments, such as those which we have discussed, are not in any sense conclusive. The difficulties in the way of any more direct proof would be, as Prof. Niles well pointed out in a recent address on this subject, even more difficult. Suppose it were desired to attempt a proof of this matter by direct rain-gauge observations. It would not do to simply compare rain-gauges in a wood and out of it, even if at a uniform height above the tops of the trees. A clearing would be necessary, and a large clearing, so that the effect of the wind might be as far as possible eliminated. Then a large extent of woods must exist; we must have a clearing in a large forest; but in this case the rain-gauge with which the forest rain-gauge would be compared would have to be located at some distance, and the topographical difference between the two sites might well account for any difference in the rainfall observed. It is pretty certain that the rainfall would *not* be the same at the two places, and it would not follow by any means that it was because of the influence of the forest. A more exact method would be to have gauges in such a forest, and then gauges in the same place after the removal of the forest, and to conduct a long series of measurements extending over fifty or a hundred years. Yet even here the well known general influence of forests on the winds might be sufficient to account for any observed difference, while a secular change in the rainfall, or a long wave of increase or decrease, would render the results valueless as indicating the effect of the forest itself.

The conclusion, therefore, to which I think we must be forced, is that we have as yet *no proof* that forests influence the mean annual rainfall, though it is not improbable that they may have some appreciable effect. And it is to be remaked that, in practice, in considering the effects of a removal of the woods, we have not to compare a region covered with forests and one entirely destitute of vegetation, but that when the forests are destroyed there generally remains a growth of underbrush, or a second growth soon springs up, or the forests are replaced by fields of grain or pastures of grass, which as regards rainfall, may have nearly if not quite as great an influence as the forest itself.

Risler concluded that although woods evaporated more than the open ground, yet they evaporated much less than ground covered with grass. It

is the neglect of this fact that often leads us to attribute to the forests effects due to entirely different causes.

The conclusions arrived at by different authorities may be quoted as follows: Marsh says. "So far as we are able to sum up the results, it would appear that in countries in the temperate zones still chiefly covered with wood, the summers will be cooler, moister, shorter, the winters milder, drier, longer, than in the same regions after the removal of the forest, and that the condensation and precipitation of atmospheric moisture would be, if not greater in total quantity, more frequent and less violent in discharge. The slender historical evidence we possess seems to point to the same conclusion, though there is some conflict of testimony and of opinion on this point."

Ebermayer says, "The woods probably effect the rainfall—only in so far as they increase the relative humidity of the air, and bring the latter nearer to its point of saturation, so that with a fall of temperature in the woods a partial precipitation of the moisture takes place more easily and in greater quantity than on unwooded ground." Ebermayer thus considers the effect of woods on evaporation to be practically *nil*, otherwise he could not have failed to see the relation between this and the precipitation. He goes on to say that "in level regions of uniform character, the influence of forests on rainfall is at any rate very small, and they have no effect on the proportional distribution through the year. With increase of elevation above the sea, the importance of the effect of woods on the rainfall increases, and the woods are therefore of more value in mountains than on plains. * * * * The cutting down of forests will at any rate affect principally the rainfall in the summer months only."

A special committee of the Royal Academy of Vienna, reporting in 1874 upon Wex's deductions said, "The question of the influence of forests upon the amount of precipitation has for some time engaged the attention of naturalists. Such an influence has been asserted partly from theoretical considerations and partly on account of the entire change presented by the climatic relations of the countries in which the forests have disappeared. * * * * It is probable that such influence exists, but while, on the one hand, its consequences may be over-estimated, on the other hand, there is want of direct proof." The commission consequently concluded that an influence of the woods upon the rainfall is probable, although direct observation does not give sufficient evidence to determine its extent or even possitively its existence.

Let us now turn our attention to the effect of forests on what becomes of the rainfall after it reaches the earth.

Briefly, it is divided into three parts; one portion flows directly from the surface, reaching the streams very quickly, and flowing off as surface water: a second portion is evaporated before it has time to penetrate far into the ground, as we often see in summer: a third portion, finally, percolates into the ground. Now of this last portion, that which percolates, a certain fraction descends until it reaches the so-called ground water, or an impervious stratum, when it flows with said ground water or along said impervious stratum, either coming to light again in springs, or adding its waters to those of some stream without coming to the surface, or reaching the sea entirely by underground channels; the re-

maining portion of the water which percolates is retained by the capillary attraction of the soil, and is finally evaporated, either from the soil directly,or by being taken up by the roots of trees, shrubs, or grasses, and evaporated from their leaves.* We may therefore say that the atmospheric precipitation is partly evaporated, in one way or another, while the remainder is finally returned to the sea, principally, yes, almost wholly, let us say for simplicity, by streams and rivers. It is convenient, nevertheless, to consider the division into three portions; that which finally evaporates, that which flows off at once, and that which percolates, simply recollecting that the former portion is composed of what quickly evaporates and of a portion of that which at first percolates to a greater or less depth. In considering the influence of woods, therefore, we must study its effect upon each of these three portions.

Now the first point which I wish to emphasize is this: that the amount of water flowing off, or the amount evaporated, or the amount percolating, is greatly, yes, enormously affected by circumstances entirely independent of forests. The division of the precipitation into these three parts is dependent, among other things, upon the following factors: the amount, and particularly the distribution of the rainfall through the year; the amount which falls in the form of snow, and the length of time the snow remains upon the ground; the temperature, and the consequent depth to which the ground freezes; the inclination of the surface; character of the soil; whether it is cultivated or not; etc., etc. The rain which falls in the summer is often almost entirely evaporated, while that which falls in spring and late autumn may in large portion reach the streams. It is a matter of common observation that a heavy storm may occur, which quickly saturates the upper layer of the soil, the remainder flowing off to the streams in rills and brooks, sometimes carrying considerable earth along and often causing considerable freshets; while if the same total quantity of rain had fallen much more slowly it would have had time not simply to saturate the topmost layer of the soil, but to penetrate to deeper layers, reach the ground water, or fill up the springs, besides a larger proportion being evaporated. Even the way in which the rain is distributed through any one week or month may therefore very greatly affect the proportion carried off by the streams or the proportion evaporated, and in general we may say that the more rapidly the rain falls the greater the percentage which flows off, and the more quickly it flows off. And the same is true in even perhaps greater degree in regard to the distribution of rainfall through the year. Suppose that, as in our Southern Atlantic States near the coast, the rain falls principally in the summer time, when the evaporation, both from the soil and from the trees, is most active; it is evident that a considerable portion of the precipitation will be evaporated, especially if the rain falls gently, and not in sudden and violent showers. Compare this with the case where the principal portion of the rain falls in late autumn, winter or early spring, when the evaporation is

*Very little water is actually absorbed by the plants. The water acts simply as a carrier. Thus Ward's experiments show that seeds, grasses, shrubs, and trees, planted in proper earth, moderately watered at first, and covered with a close frame of glass, live for many months, and even for years, with only the original store of air and water. In one experiment, a spire of grass and a fern flourished for eighteen years in a corked bottle.

not energetic, and when the ground is perhaps less prepared to absorb moisture. In this case the precipitation will be principally shed from the surface and gathered rapidly into the streams. Different parts of the country, then, in which the rainfall is differently distributed, will show entirely different proportions flowing off, entirely different proportions evaporated, entirely different proportions percolated. Nor do we even require to compare different portions of the country. Even in the same spot—right here in Boston, for instance—the rainfall may be very differently distributed this year from the way it was distributed last year, or the way it will be distributed next year; and consequently the proportions flowing off and evaporated will be correspondingly different. In fact, the percentage of the rainfall collected, on the Cochituate watershed, since 1877, has varied from 59.8 to 28.7 inches. In 1874 and in 1880 almost exactly the same quantity of rain fell, viz.: 36 inches. but in 1874, 54.3 per cent. was collected, and in 1880, 28.7 per cent.

Now all this may seem to have little or nothing to do with forests, but I wish to emphasize the fact that forests constitute but one factor, and not always the most important one, affecting the flow of streams, and that consequently we must proceed very cautiously in attributing certain supposed effects to the agency of forests. The varying effects of the other factors which have been enumerated cannot be reduced to figures or predicted beforehand, and until we can do this I consider that it will be an absolute impossibility, in the case of large streams, to draw any definite conclusions regarding the effect of forests, from observations on the flow itself. Supposing that in a region where the forests have been extensively removed, we can prove that the flow of a stream has been growing more variable; it does not therefore follow that it is due to the cutting down of the trees; or suppose that we can show that the discharge of the stream has been getting smaller; it does not therefore follow that the removal of the forests has diminished the rainfall. Yet such deductions are constantly being made. I do not dispute the fact that the destruction of forests renders the flow of the streams more variable, but I desire to call attention to the need of caution in drawing conclusions from data regarding the flow of large streams, which is affected by so many factors, and to the necessity of basing conclusions regarding the influence of forests upon a comparative study of the effects of forests upon the three factors,—evaporation, percolation, and surface discharge,—under otherwise similar conditions. Such studies have been made, and I will now proceed to give their results, and to briefly point out the way in which forests affect the division of the rainfall into its three component parts. First, as regards the precipitation itself, the experiments of Ebermayer in Bavaria showed that about one-quarter of the rainfall is intercepted by the trees, and never reaches the ground, being very soon evaporated. The same authority found that the annual evaporation from a free water-surface in a forest was but 36 per cent. of that on cleared ground; and as this proportion was about the same in all months of the year, it is evidently due, not to the difference in temperature of air, but to the smaller amount of wind in the forest. The evaporation from moist earth was found to be from 40 to 70 per cent, of that in cleared ground, when the earth was stripped of moss and leaves, but the effect of the covering of moss and leaves was to

still further reduce the evaporation, to from 30 to 50 per cent. of that without the covering. In other words, if the evaporation from uncovered moist earth in cleared ground be 100, then that from an uncovered forest ground would be, on an average through the year, 38, and on forest ground covered with moss and leaves it would be 15. This diminution of evaporation was moreover greatest in the summer. The very great diminution in evaporation in woods was therefore found to more than make up for the 25 per cent. of the rainfall which is intercepted by the trees, and never reaches the ground; and the covering of moss and leaves was proved to be as effective in diminishing the evaporation as the woods as such. But we must not omit to consider the fact that a large portion of the water percolating is finally evaporated—that trees evaporate large quantities of water through their leaves and branches. Regarding this point, however, there are no very satisfactory experiments, and the results thus far reached have been, I believe, discordant. For instance, Schleider concluded that the trees of a wood evaporated three times as much water as would be evaporated from an equal water surface, while Unger found exactly the reverse, viz: that the water surface would evaporate three times as much as the plant. In the face of such disagreement, definite results are impossible, but since the observations of Ebermayer showed that the absolute amount of vapor in the air in forests was not perceptibly greater than in cleared ground it seems impossible that trees can be as great evaporators as some have made out. Marsh therefore concludes, from Ebermayer's experiments, and those of Risler, that the total effect of forests on evaporation is very small, and may be neglected; while Ebermayer comes to the result that woods evaporate rather more than cleared ground. It is important to remember in this connection that if woods have no effect upon evaporation, it is difficult to see how they can have any effect upon the rainfall. For they cannot alter the amount of vapor brought from the ocean, and can only increase the rainfall by increasing the evaporation, thus supplying aqueous vapor to the atmosphere, to be again precipitated, again evaporated.

It must also be borne in mind in this connection that in regions where the snow lies long upon the ground it may condense considerable moisture —some say as much as is evaporated—so that in such regions the forests by preserving the snows might diminish considerably the resultant evaporation.

Second, in regard to the effect of woods upon the percolation, probably forests may increase or diminish it according to circumstances. The roots, no doubt, if not too thick, as in the case of grass and turf, facilitate percolation, and even sometimes enable the water to filter along them through impervious strata to pervious strata beneath. In La Brenne, a tract of 200,000 acres resting on an impermeable sub-stratum of argillaceous earth, which ten centuries ago was covered with forests interspersed with fertile and salubrious meadows and pastures, has been converted, by the destruction of the woods, into a vast expanse of pestilential pools and marshes. And in Holland, drainage is sometimes facilitated artificially by driving into the ground several hundred stakes per acre, along which the water can percolate to greater depth than it otherwise would. Then, again, the vegetable mould and moss with which the ground in forests is

covered absorbs the water, prevents its running off and allows it to percolate gradually. The soil in forests is generally moist, and as the evaporation is small from the ground itself, it is very plain that the effect of forests is to diminish the proportion of the rainfall shed directly from the surface, and to increase the initial percolation. Direct experiments confirm this result. Ebermayer found that during the year 20 per cent. more water percolated to a depth of 2 feet in forests than in cleared ground, notwithstanding the loss of 26 per cent. of the rainfall intercepted by the trees. But notice the remarkable result, that at a depth of 4 feet, or below the roots of the trees, considerably less, 15 per cent., percolated in the forest. The roots of the trees, had more than absorbed the excess at 2 feet, to evaporate it through the leaves. Forests, then, seemed to slightly decrease the percolation in Bavaria. And it is important to notice that when the surface of the ground is covered with a thick network of roots, or of thick grass turf, the percolation may be greatly hindered. Moss and leaves are much more favorable, but if the moss is too thick it will be a sponge of too great capacity, and will exercise just the opposite effect, holding the water, keeping it from percolating, and gradually evaporating it. But it is when we come to consider the percolation at different seasons that we begin to see the full effect of the forests, for we then find the following remarkable results: in winter, the percolation in forests to a depth of 4 feet was one-half that in open ground; in spring, the percolation in forests was slightly more than in open ground; in summer, the percolation, in forests was nearly three times that in open ground; and in autumn, the percolation was 12 per cent. less in woods than in open ground. These results are for Bavaria, but I think that they may be very greatly modified in climates that are different. In Germany, two-thirds of the rainfall comes in winter and spring, but in a region, for instance, where the rain comes almost entirely in the summer and autumn, I think the total annual percolation will be considerably greater in woods than out of them.

On open ground, a large portion of the rain in summer is evaporated or carried off by the streams, often not penetrating the soil beyond a few inches. It is a French saying "Summer rain wets nothing." The forests decrease the quantity flowing off and allow it to percolate gradually.

Then again, in regions like our own, where the snows are deeper and last longer, and where the ground is therefore better protected in winter, there is no doubt that the percolation in woods will be in winter much greater than according to Ebermayer's experiments. That physicist found that the ground in Bavaria froze just as deep in forests as in open spaces, but in regions like our own this will not be found to be the case. In fact, it is stated on good authority that where the snow lies deep and long the ground is sometimes not frozen at all, and there seems little doubt that bare ground freezes deeper than forest ground, so that when the forest snows melt they are much more readily taken up by the soil than in cleared ground.

As a recent writer expresses it: "So also, in colder latitudes, where, during the wintry months, the moisture of the atmosphere is precipitated in the form of snow, and accumulates often to a great depth, the conservative influence of the forest is very obvious. Sheltered from the winds, and to a considerable degree from the cold, the snows themselves offer a

protecting covering. The earth seldom freezes in the forest and the warmth from the ground below gradually melts the snow and so feeds the streams and springs as to maintain in them an equable flow. As the warmer sun and wind of advancing spring time begin to heat the surface of the ground, the screen of the trees prevents their influences from being so sensibly felt in the woods as in the open fields, and the result is that the snows dissolve gradually and the resultant water, sinking in the first place and for the most part into the spongy, leafy soil, flows away, gently as do the rains of summer time, into the valleys and fields below. But when the forests have been removed, the case is very different. The snows, no longer screened from the sun's rays and the warm winds by the interposed foliage, or even the naked trunks of the trees, are rapidly dissolved, often before the earth beneath, or the ground over which the waters must flow has been unlocked from the wintry frosts. As a necessary result, thousands of rivulets are formed almost at once which are precipitated into the adjacent stream whose rapidly increased volumes are hurried to the larger streams below, and thus we have our spring floods, often so destructive to property as well as life."*

The preservation of the snows by the forests and their consequently slower melting, is of especial importance in the case of streams which flow for long distances from north to south, like the Merrimac, the Connecticut, and others. Did the snows go off suddenly, great freshets would result, but as the spring advances northward, the snows from forest regions go off gradually, and the spring freshets are much diminished in violence.

Briefly stated, then, it seems probable that in the United States the effect of forests on percolation is to increase its amount, particularly in the summer. Now assuming that the woods have no great effect upon evaporation, or that if they have they increase it, and that they increase the percolation, it follows that they must diminish the quantity directly flowing off; and this is a matter of common observation. By the presence of the layer of vegetable mould and leaves, and by the obstruction offered by the trunks and roots, they retard the discharge of the rains and especially of the snows, and cause them to be in large part retained and given out gradually. As regards the total annual quantity discharged by streams, forests should have little or no effect provided that they have no effect upon the evaporation; although by facilitating percolation, they may increase the discharge of subterranean streams, thus slightly diminishing that of surface streams. Their function is principally, it would seem, to increase the percolation at the expense of the water directly flowing off: and by exercising this function particularly in the summer time, they serve as equalizers of flow, maintaining comparatively constant the flow of springs, and keeping up the streams when they would otherwise go very low. They are the reservoirs which feed the springs and streams, and of which we should hesitate to diminish the capacity. They are equalizers —not only of flow, but of temperature and humidity. The removal of forests therefore no doubt tends to increase the violence of freshets, and to increase the ratio of the maximum to the minimum flow, which ratio is an index of the variability of a stream. But it is extremely doubtful whether it can be proved—certainly it has not yet been proved—that the

*Popular Science Monthly, 1881, page 180.

removal of forests decreases the total quantity flowing off and I have referred already to the difficulty of proving or disproving such statements.

This effect of forests in diminishing the quantity flowing off, and mitigating the violence of freshets, is particularly important in mountainous districts; hence in such districts the preservation of forests is especially important. Many instances could be adduced of small streams in the Alps which by the destruction of forests have been made extremely variable. Where the steep slopes of the mountains have been cleared of woods, the waters which formerly found their way gradually to the streams, now course down the mountain sides with tremendous violence, swelling the streams enormously in a few hours. Marsh relates regarding the rapidity with which the Ardiche, a small tributary of the Rhone, rises and falls, that in the flood of 1846 women who were washing in the bed of the river had not time to save their linen, and barely escaped with their lives; and the Beaume, a tributary of the Ardiche, rose at one time to the height of 35 feet but was fordable again on the evening of the same day. The rainfall, however, on the basin of this stream, has been known to amount to 31 inches within 21 hours. Some of our western streams, too, which drain a mountainous country denuded of trees, rise and fall very quickly, and I am told that travellers in the territories make it a rule to camp on the farther side of a stream which they reach near evening, lest it should rise in the night so as to be impassable.

Although the presence of forests operates generally to increase the yield of springs, there are some cases where they exercise a contrary effect, namely, in the region of sand hills in New Jersey and along the southern Atlantic coast. Here the soil of the hills is more permeable and less retentive than that in forests, and the rain percolates more freely where the forests are absent. The evaporation is also less.

Another effect of forests upon flow should here be alluded to, viz : that by their roots as well as by the covering of moss and mould they hold the soil together and prevent its being washed away into the streams. Rivers draining a forest region should therefore carry less sediment than those draining a topographically similar cleared region, and they should therefore offer less obstruction to navigation due to the formation of the sand-bars along their channels or at their mouths. The amount of sediment carried annually to the sea by large streams may not be generally appreciated. To give an illustration, I will say that it has been calculated that the Mississippi river carries annually to the Gulf of Mexico 406,250,000 tons of sediment, which would cover an area of one square mile to a depth of 241 feet. To express it in a way more easy of comprehension, if this mass were transported to the sea in large steamers of 5000 tons tonnage, one would have to pass every 6 minutes during the year. The effect of forests in mitigating such extensive denudation as this is not to be neglected. The ground in forests, being larger and more effectually covered with snow than that in cleared regions; where the snow drifts at the mercy of the wind, the earth is not exposed to that alternate freezing and thawing which so disintegrates it. When the spring freshets come, therefore, not only does the snow go off more slowly in the woods but it takes much less soil with it.

The river Po transports annually to the sea not less than 55,000,000 cubic yards of silt, carrying the coast line out 200 feet; and the great river system of the Ganges carries to the sea the enormous quantity of 40,000,000,000 cubic feet in four months. If this were transported by vessels of 5000 tons burthen one of these would have to sail every two minutes during the time. When we remember the enormous rainfall in this region, which has been 805 inches in one year, with 366 inches in a single month, we can understand the tremendous effect of such a torrent on a denuded, bare surface. Mountain slides, too, caused by a sudden percolation of a considerable quantity of water between a pervious and an impervious stratum, are frequently aided by the cutting down of the forests.

In closing this paper, a few statistics regarding the forests of this country may not be out of place. The reckless inroads already made on some of our great forest regions, and their annual contribution to our lumber supply have been so large that many of them must be exhausted in a comparatively few years, and a great development in the lumber industry in other regions must soon take place. Nevertheless, as Prof. Sargent says, "fire and browsing animals inflict greater permanent injury upon the forests of this country than the axe, recklessly and wastefully as it is generally used against them." The statistics of the tenth census show that, in 1880, the amount of white pine (first growth) still standing was only sufficient to supply the demand for eleven years, at the rate at which it was then being cut. "The lumber cut in a single year from the district of Michigan, Wisconsin and Minnesota would load a train of cars 7,000 miles in length." The southern pines are more extensive and less used, and at the present rate will last nearly 150 years, but the annual destruction of these forests in the south by fire is enormous, and, if continued, will seriously reduce the length of time that their supply will last. In the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas, Arkansas, Missouri, Kentucky, and Tennessee, that is, in the southern states, the number of acres of forest burned over in the census year ending May 31, 1880, were 6,428,070, and the value of the property destroyed, $7,414,195. In Massachusetts alone, in the census year, 13,899 acres of timber lands were burned, and the value of property destroyed was $102,262.

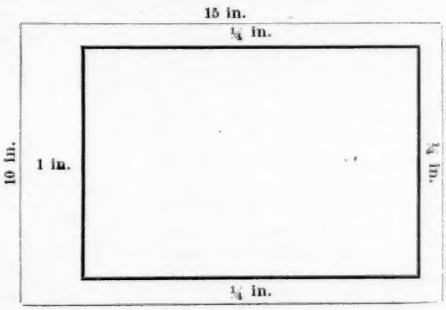
The forests in the West are very large in extent, but serious inroads are being made here by fire. Maj. Powell states that he has "witnessed two fires in Colorado, each of which destroyed more timber than all that used by the citizens of that State from its settlement to the present date, and at least three in Utah, each of which had destroyed more timber than that taken by the population of the Territory since its occupation." The total number of acres burned in the United States during the census year was 10,274,089, the value of property destroyed being $25,462,250. The effect of fires is not to be estimated alone by the actual destruction of merchantable lumber, as they also destroy young trees and shoots and seriously threaten the timber supply of the future. Our railroads, again, consume about 60,000,000 of ties annually, and these are generally cut from vigorous young trees. If we assume two ties to a tree, we have an annual cut of 30,000,000 trees for this purpose alone.

EXCHANGE OF SKETCHES.

A scheme involving the contribution by each member of a sketch of some device of general interest was first presented to this Association in June, 1884, by W. B. Sherman, and at the next annual meeting [June, 1885] ten sketches were submitted and in June, 1886, this number was increased to thirteen.

The plan contemplated that each member should prepare or have prepared by some of the well known processes of reproduction; (blue prints, hectograph, etc.,) a sufficient number of copies to allow one for each member present.

The sketches were to be of uniform size 10 in. x 15 in., as follows:



with the title and name of contributor in the upper right hand corner.

The subject was to be any device, as a peculiar wrench, gate box, service box, hydrant, air valve or any structure as a dam, tank or stand pipe.

The device or structure was not to be necessarily original with the contributor, but might be anything of general interest.

As will be seen the plan has not as yet been generally adopted, by members of this Association, but it is hoped that at the next annual meeting it will receive a more cordial support. It has already been partially adopted by the Connecticut C. E. and S. Association.

Anyone who has heard Mr. Sherman's appeal in behalf of the plan must realize its possibilities and the following list of the contents of a portfolio owned by W. H. Richards, (a member of both Associations) shows how valuable a collection can be possessed by every member if sufficient interest is taken in the subject.

To those unacquainted with the method, reproduction by the blue process seems quite formidable, but it is really quite easy and any person sufficiently ingenious to be a Superintendent of Water Works, can accomplish it. Should lack of time be used as an excuse, a tracing of the sketch, such as may be made on the ordinary tracing cloth by any draughtsman, can be sent to the Mass. Inst. of Technology and blue print copies will be made by them, for 5 cents each.

Members are reminded that it is desirable to have sketches of the uniform size mentioned above.

Either of the committee on sketches, W. B. Sherman of Providence, R. I., or W. H. Richards, of New London, Conn., will gladly furnish any advice as to a subject, or the process of reproduction.

It is to be hoped that every member will make a special effort to make the scheme a success, for without co-operation it cannot become so, and another year of partial failure will tend to discourage those who are already interested.

LIST OF SKETCHES IN THE PORTFOLIO OF W. H. RICHARDS.

Sketches marked [*] were not submitted to the New England Water Works Association.

*Table of Discharge of Sewers, W. H. Richards.
*Effluent Pipe, C. E. Chandler.
Duties of Pumping Engines, W. B. Sherman.
*Dams and Embankments, compiled by W. H. Richards.
*Dam Ashland Cotton Co., C. E. Chandler.
*Greenville Dam, C. E. Chandler.
*Hering's Table of Flow of Pipe Sewers, W. H. Richards.
*Adjustable Effluent Pipe, E. P. Auger.
Main Pipe Plugs, W. R. Billings.
*Diagram of Consumption, Edwin Darling.
Dam West Haven Water Co., E. H. Phipps.
*Flush Tank for Sewers, F. F. Weld.
Anchor Ice at N. L. Water Works, W. H. Richards.
Weir at N. B. Water Works, A. B. Drake.
Meter Test, John C. Chase.
Composite Pipe, Sherman E. Grannis.
Tapping Wrought Iron Pipe, (2 sketches) F. E. Hall.
Tool House, (2 sketches) R. C. P. Coggeshall.
Somerville Water Works, N. Dennet.
Chronograph, Hiram Nevons.
*Stand for Folios, C. E. Chandler.
Foundation on Quick Sand, W. B. Sherman.
*Greenville Dam, H. Cook.
*Norwich Water Works, W. H. Burnett.
*Masonry, E. A. Hill.
*Green Meadow Reservoir, R. D. Barnes.
*Catch Basin, E. P. Auger.
*Sewer Overflow, C. E. Chandler.
*Section Map, E. P. Auger.
*Sewer Bids, C. E. Chandler.
*Diagram of Reservoir Walls, W. H. Burnett.
Lever for Sheeting, W. B. Sherman.

*Ventilation of Manholes, C. E. Chandler.
*Catch Basin, W. H. Burnett.
Water Cart Hydrant and Tap Cleaner, R. C. P. Coggeshall.
Stand Pipe, J. C. Hancock.
Gate Box and Service Pipe, W. H. Richards.
Water Cooler for Drinking Fountain, T. C. Lovell.
Screens and Pump Well, (2 sheets) A. H. Howland.
Eel Traps, S. E. Grannis.
Fountain Basin Overflow, W. R. Billings.
Connections for Lead Pipe. H. N. Hyde, Jr.
Weights of Lead Pipe, W. B. Sherman.
Blue Print Frame, W. B. Sherman.
*Plumbing, W. H. Richards.

SINKING FUNDS.

By the Junior Editor.

The following table may be a help in answering the question, "How much money must be set aside each year, as a contribution to a sinking fund which shall pay a given loan at maturity," The use of the table can best be explained by an example. If the sum of $84.74 be set aside at the beginning of each year and the fund thus created return an income of 3 per cent., it will amount to $1000 in ten years. Again, a loan of $1000, having thirty years to run, will be paid for by a yearly appropriation of $17.14 if these appropriations be invested so as to yield a 4 per cent. income. The table is computed from the formula

$$s = \frac{r\,A}{(1+r)^{n+1}-(1+r)}$$

Where s = amount to be set aside at beginning of each year

r = rate of interest received from investments

n = number of years for payment

A = amount to be raised in n years.

Table giving values of s, when A=$1000, with different values for n and r:

Values of *n*	Values of *r*					
	3	*3½*	*4*	*4½*	*5*	*6*
10 years	84.74	82.43	80.16	77.88	75.72	71.57
20 "	36.16	34.17	32.31	30.50	28.80	26.79
30 "	20.44	18.65	17.14	15.60	14.30	11.93
40 "	12.93	11.43	10.12	8.94	7.88	6.15
50 "	8.61	7.37	6.31	5.36	4.55	3.25

Values of s for any amount larger than $1000 will be obtained by simple multiplication.

The formula from which I have computed the foregoing table is not original with me but was evolved at my request by my mathematical friend and mentor, Mr. J. C. Bartlett, now Supt. of Schools in Taunton, and for the benefit of those who, like myself, dislike to use a formula whose origin is not clear, the work of evolution is here given:

At end 1st year $A_1 = s\,(1+r)$

" 2d " $A_2 = s\,(1+r)^2+s\,(1+r)$

" 3d " $A_3 = s\,(1+r)^3+s\,(1+r)^2+s\,(1+r)$

" n years $A = s\,(1+r)^n+s\,(1+r)^{n-1}+$&c.$+s\,(1+r)$

From which $A = s\,[(1+r)^n+(1+r)^{n-1}+$&c.$+(1+r)]$ (1)

That part of the right hand member of the equation (1) which is between the brackets is a simple geometrical progression, but in order to make it available we must have an expression for its sum. This is

obtained by use of the ordinary formula for the sum of a geometrical progression

$$S = \frac{R\,L - a}{R - 1} \qquad (2)$$

In this case the ratio $R = (1+r)$

the first term $a = (1+r)$

the last term $L = (1+r)^n$

Substituting these values in (2) the sum

$$S = \frac{(1+r)\,(1+r)^n - (1+r)}{(1+r) - 1} = \frac{(1+r)^{n+1} - (1+r)}{r} \qquad (3)$$

The expression (3) can now take the place of so much of the right hand member of (1) as is between the brackets, and we have

$$A = \frac{s}{r}(1+r)^{n+1} - (1+r) \qquad (4)$$

and solving with regard to s

$$s = \frac{r\,A}{(1+r)^{n+1} - (1+r)} \qquad (5)$$

A formula to include the case in which a sinking fund is begun upon a capital already invested will be given in the next number of the Journal.

Table of Contents.

Page.

Proceedings.

Quarterly Meeting, March 9, 1887..... 18

Papers.

A Resource of Cheap Water for the People, Thos. M. Stetson, Esq..... 3

The Driven Well as a means of Water Supply, Albert F. Noyes, C. E. 19

Editorial.

The New Bedford Water Act.....3 and 17

Sinking Funds No. 2..... 27

Statistics from Annual Reports..... 29

Advertisements..... .....